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Exterior Ballistics of the AR-15 Rifle

by Robert W. Cross

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AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA

FOREWORD

This report was prepared by the Weapons Laboratory, Detachment No. 4, Aeronautical Systems Division of the Department of the Air Force. All work was performed by the Weapons Laboratory personnel under the direct supervision of Mr. Gerald A. Gustafson, Technical Director.

This work was accomplished under project No. 912A-0000-97205, at the request of Headquarters USAF.

ABSTRACT

This study was conducted to provide information which could serve as a basis for certain design decisions involving the AR-15 rifle. Bullet stability, lethality, penetration, and deflection were subjects of the physical testing conducted. In addition, bullet shape and muzzle velocity with regard to stability are discussed.

The exterior ballistic theory concerning the Remington 0.223 caliber bullet predicts that bullet instability can be expected if the bullet is fired through a barrel with a one-turn-in-14-in. twist in an air density greater than that which occurs at 0° F at sea level. Further, the theory predicts that the bullet will be stable if fired through a barrel with a one-turn-in-12-in. twist in an air density up to that which occurs at -100° F at sea level. Confirmatory tests conducted at the Climatic Laboratory indicate the predicted instability when using the one-turn-in-14-in. barrel and indicate the stability of bullets fired from the one-turn-in-12-in. barrel in conditions down to -65° F at sea level.

Other tests during this study indicate that there is no significant difference in the lethality of bullets fired from either barrel. Also, no severe deflection or break-up problems were noted when the caliber 0.223 bullet was fired through brush or other natural cover, and physical testing proved that the bullet is capable of penetrating and killing a wide variety of soft-material targets.

A study indicates that substitution of a flat-base bullet for the boat-tail bullet will result in a stable projectile when fired from a one-turn-in-14-in. barrel; however, there will be an unacceptable attendant degradation of the exterior ballistics.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

G. M. McNeese

G. M. McNEESE
Colonel, USAF
Director

LIST OF ILLUSTRATIONS

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SECTION I - INTRODUCTION

The purpose of this study was to provide information which could be used as a basis for certain design decisions involving the AR-15 rifle. The major portion of this study is devoted to bullet stability; however, other considerations such as lethality, penetration, and bullet deflection are also covered.

The exterior ballistic theory given in reference 6 concerning the stability of the Remington Caliber 0.223 bullet predicts that bullet instability can be expected at temperatures below $0^{o}F$ at sea level when the bullet is fired from a barrel with one-turn-in-14-in. rifling. Further, the theory predicts that a modification of the barrel to a rifling of one turn in 12 in. would stabilize the bullet sufficiently. Confirmatory tests were carried out in the Climatic Laboratory at Eglin Air Force Base, Florida. A detailed discussion of the ballistic theory appears in the Appendix to this report.

While factors such as stability can be predicted from the theory, it is not possible to determine by theory alone any change in lethality which might have been brought about by the modification. Therefore, a series of impact tests in which both a modified AR-15 rifle and an unmodified AR-15 rifle were fired into 20 percent gelatin was conducted at the Aerojet-General Corporation test facility in Chino Hills, California. The results of these tests show no degradation of performance was caused by the modification.

A possible fix to the stability problem would be to substitute a 55-grain, flat-base bullet in place of the 55-grain boat-tail bullet now in use. The flat-base bullet should stabilize the bullet to $-65^{o}F$ as predicted. It is further true that the flat-base bullet will probably result in a more accurate ammunition for short ranges. For some applications then, the flat-base bullet can be used. One of these applications might be for competitive shooting at short ranges.

However, there are also some disadvantages in using a flat-base bullet. One of these is that a lower velocity at any given range is brought about by the higher drag. Another factor is that flat-base bullets are affected more by crosswinds than are boat-tail bullets. This results in a greater dispersion on long-range shots in combat. The lower velocity will result in reduced lethality on impact, and the larger dispersion will result in fewer targets hit. Both of these contribute to a reduction in the combat effectiveness of the weapon.

For these same reasons, a boat-tail bullet is now standard in the M14, 7.62mm rifle.

One possible consequence to increasing the rate of twist in the barrel is a reduction in muzzle velocity. The amount of energy involved in the spinning of the projectile (rotational energy) is less than 0.2% of the translational energy (muzzle energy). The variation in rotational energy involved in changing from one turn in 14 in. to one turn in 12 in. is less than 0.05%. The resultant velocity change predicted as a result of changing the twist is less than 1 ft per sec. This variation is far below the velocity variation expected from round to round with the highest quality ammunition, and thus, is not considered to be of importance.

Tests were conducted to determine performance characteristics of the Caliber 0.223 bullet with respect to penetration, deflection, and break-up. Tests performed by personnel of Detachment 4, ASD, using a rifle with a one-turn in 14 inch barrel indicate the following:

a. The Caliber 0.223 bullet will penetrate through 0.25 in. of steel plates at ranges slightly greater than 100 yd.

b. The Caliber 0.223 bullet will penetrate through more than three layers of spaced sheet metal, such as that used in the bodies of jeeps and trucks.

c. The Caliber 0.223 bullet will penetrate through more than 10 in. of pine boards.

d. The Caliber 0.223 bullet does not break up under normal usage.

SECTION 2 - DESCRIPTION OF ITEMS TESTED

A total of nine rifles were used in this test: four AR-15's, two M-14's, and three Remington 700 ADL's. AR-15 Nos. 1 and 2 were rifles with one-turn-in-14-in. twists, and AR-15 Nos. 3 and 4 were rifles with one-turn-in-12-in. twists. The M-14 rifles were manufactured by the Springfield Armory and were identical except for serial numbers. The three Remington 700 ADL rifles were identical except for the barrels--one had a one-turn-in-10-in. twist, one had a one-turn-in-12-in. twist, and one had a one-turn-in-14-in. twist.

The AR-15 rifles (Fig. 1) were equipped with three-power Inerga scopes, and the Remington rifles (Fig. 2) were equipped with Lyman Super Targetspot scopes. The caliber 0.223 Remington ammunition was issue ammunition from Lot No. R. A. 500. The 7.62mm NATO ammunition used was from Functional Lot No. RA-L85057. Two 10-shot groups were fired utilizing Caliber 0.223 Winchester-Western ammunition with an unknown lot number.

Fig. 1: AR-15 Rifle and Test Setup at the Climatic Laboratory.

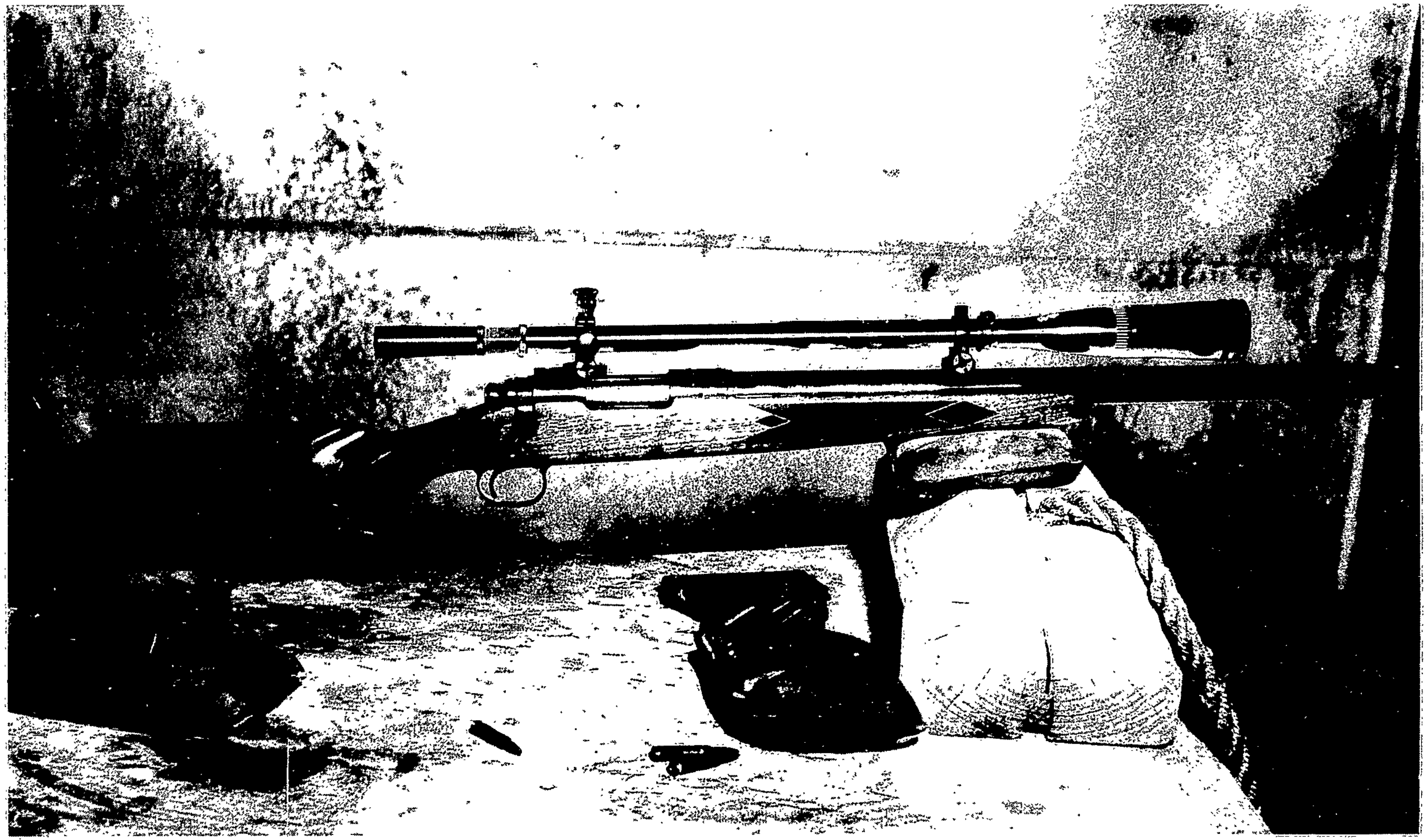

Fig. 2: Remington Model 700 ADL Rifle and Test Setup at the Climatic Laboratory.

SECTION 3 - TEST PROCEDURES, RESULTS, AND DISCUSSION

BULLET STABILITY

It should be noted that air density is a function of temperature and atmospheric pressure and to some extent, humidity. Figs. 3 and 4 show how relative density varies with altitude and temperature, respectively. The ordinate values in these graphs may be used as multipliers to find new stability factors when s_1 is given for the 70° F, sea level condition.

Fig. 4 shows the caliber 0.223 Remington bullet stability factor as a function of air density for bullets fired from both the one-turn-in-14-in. and the one-turn-in-12-in. barrels at the same muzzle velocity (3250 fps). The density of standard air is assumed to be 0.0749 lb per ft^3 at 70° and 29.9 in. Hg. These curves are all based on an assumed value for s equal to 1.16 at 70° and sea level.

From Figs. 3, 4, and 5, it can be predicted that the caliber 0.223 Remington bullet from the one-turn-in-14-in. barrel will become unstable at a temperature of 0° F at sea level and that the same bullet from the one-turn-in-12-in. barrel will become unstable at a temperature of about -100° F.

The stability factor for the caliber .223 Remington bullet has been determined experimentally and theoretically with reasonable agreement. The value for the stability factor (s) as given in reference 1 is 1.13. This value was obtained by firing through yaw cards. Another estimate of s was made by the General Electric Company using carefully determined dimensions of the bullet. From these dimensions the axial and transverse moments of inertia of the bullet were computed and from these the stability factor was determined. This method yielded a value of 1.14.

It has been verbally stated by personnel at the Ballistics Research Laboratories at Aberdeen Proving Ground, Maryland, that a spark range determination of stability factor yielded a value at 1.20. The spark range determination is inherently the most accurate method. Another determination of stability factor also performed at Aberdeen using a dynamic ballance technique for determining the moments was said to yield a value of 1.16. All of these values are for a standard 70° F temperature and 29.9 in. Hg atmospheric pressure. These variations (1.13 to 1.20) are within the lot-to-lot variations encountered in ammunition production.

The 7.62 (NATO) M80 bullet when fired from an M-14 rifle is reported to have a stability factor in excess of 2. As tests bear out, there is no stability problem with this bullet in air.

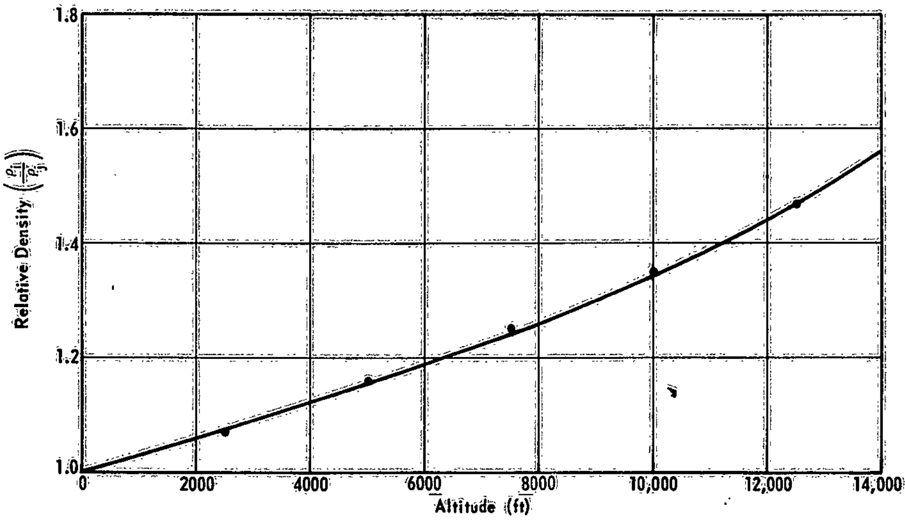

Fig. 3: Relative Density of Dry Air at Sea Level to Air at Altitude at a Constant 70° F Temperature.

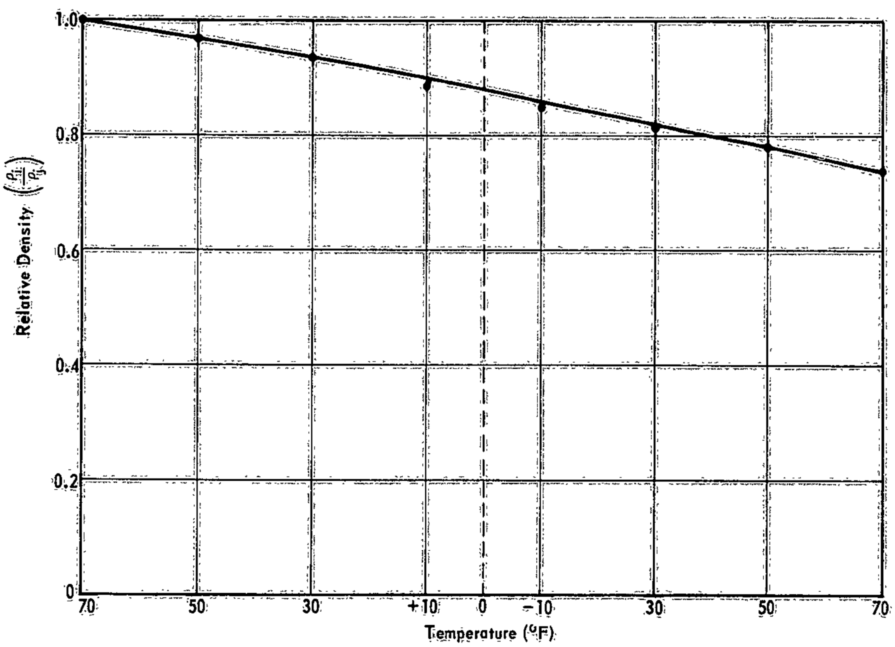

Fig. 4: Relative Density of Dry Air at 70° F to Air at Lower Temperatures at a Pressure Constant of 30 in. Hg.

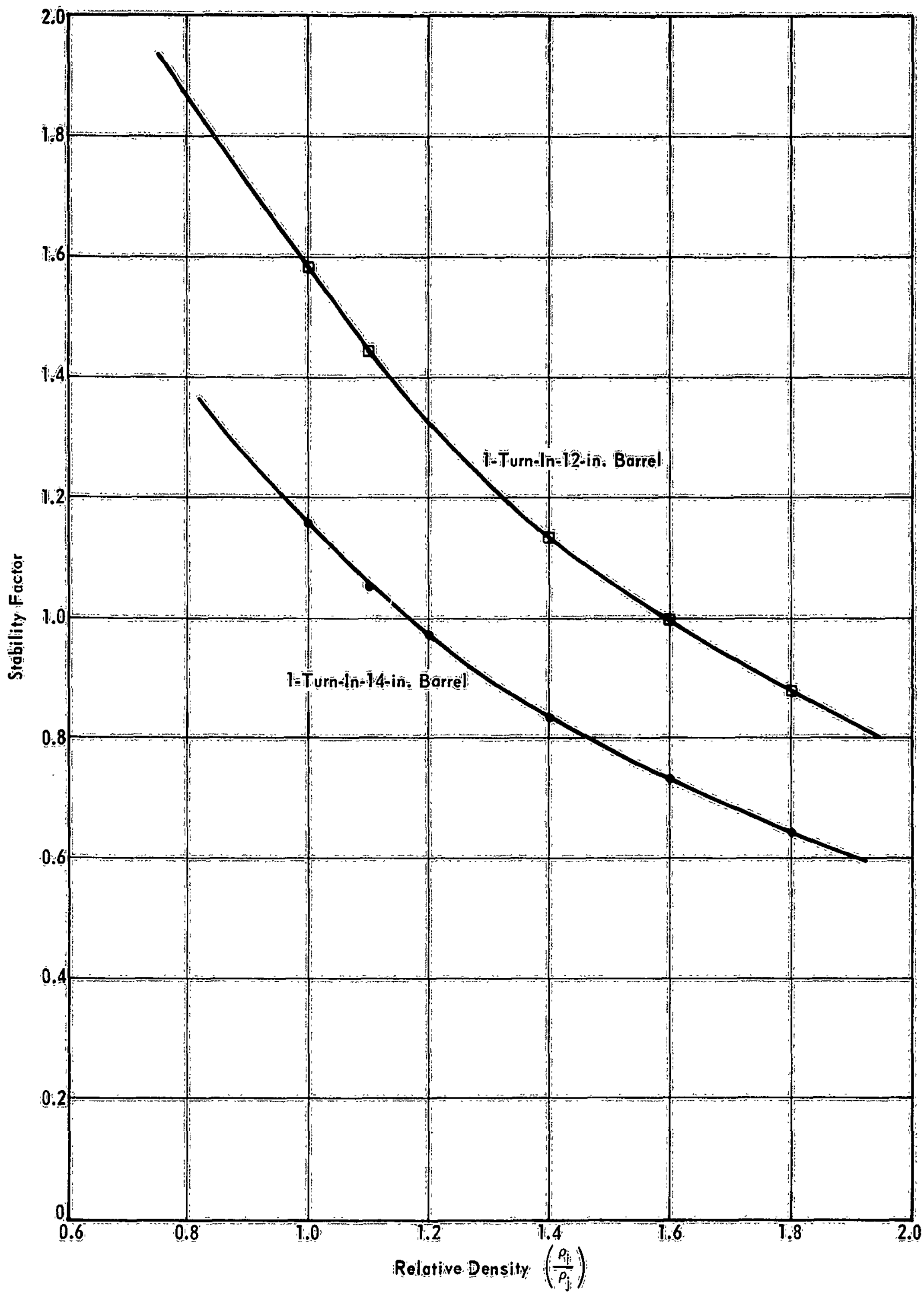

Fig. 5: Caliber 0.223 Remington Bullet Computed Stability Factor vs Relative Density of Air at Sea Level and 70° F.

CONFIRMATORY TESTS. In order to confirm the stability values derived from the computations, it was necessary to conduct a series of firing tests. A climatically controlled, properly instrumented, aero-ballistic range was not available for these experiments. Because of this, other than the usual techniques for stability testing were applied.

A yawing bullet will be subjected to two forces not experienced by a well-stabilized bullet. First, the drag will be increased because of the increased area presented. This increase is called the "yaw-drag." Second, the bullet will experience lift because of the resultant force on the projectile forcing it away from its instantaneous trajectory. Both of these forces introduce impact errors. For this reason, a greater bullet dispersion can be expected when using unstable bullets or marginally stable bullets than when stable bullets are used.

A firing test program was devised to demonstrate the effect of air density on the dispersion of the bullets. These experiments were conducted in the Climatic Laboratory at Eglin Air Force Base, Florida. By conducting these tests concurrently with other tests, it was possible to obtain data in environmental conditions ranging from $+16^{o}F$ to $-65^{o}F$ which represent a significant change of air density and spans the temperature range of interest. Data from these tests were supplemented by firings outside the Climatic Laboratory with a good degree of correlation.

TEST SET-UP. Limitations of time and resources did not allow a completely pure scientific experiment to be performed. Many unmeasured factors have crept into the data, some of which are discussed. It should be pointed out, however, that for the most part the experiments yielded results which are consistent with the theory and which are directly applicable to real combat situations. For this reason it is felt that the experiments reported have even higher value than if they had been generated in an idealized set of conditions.

The maximum range possible within the Climatic Laboratory without interfering with other tests was 220 ft. This distance has been used throughout the ballistic experiments and from the data it is seen to be adequate.

The firing-in butt was constructed of steel similar to but larger than the small commercially available bullet stops. It was realized that these bullets would crater the back plate on impact even though it was set at an obliquity of 45^{o} and that back splatter would be a severe problem. Therefore, a 2-in. wooden shield was placed in front of the bullet stop to catch splatter.

TEST PROCEDURES. All firing was performed under identical conditions using bench-rest techniques. Such a technique yields the minimum aiming errors with the equipment available for the experiments.

The temperature of all equipment used in the experiments was brought to the chamber temperature by soaking for at least eight hours. Cold-soaking the ammunition may have caused different group sizes than would have been obtained by using ammunition at constant and higher temperature, e.g., +60°F.

It was possible to run only one experiment to ascertain how much the cold ammunition contributed to the total dispersion. This trial using ammunition at +60°F in a test chamber at -25° F produced a smaller group than ammunition at -25° F. The margin of reduction was within the expected limits for group-to-group variation. Based on past experience, changes in group sizes with changes in ammunition temperature is more likely to be due to improper matching of ammunition to the dynamic characteristics of the gun and particularly the barrel.

The resolution of this problem is not possible without much more experimentation, and one can question the military value of such a study. There are several good texts which discuss the matching of ammunition to gun dynamics in order to reduce bullet dispersion. Probably the best among these is "The British Text Book of Small Arms."

Ten-shot groups were fired on each target. Every shot was carefully aimed under as near identical conditions as possible. The firing rate was not carefully controlled; however, at least 10 sec. and not more than 30 seconds elapsed between shots. The firing rate was strongly dependent upon conditions in the chamber not under the control of the test personnel. Such things as fogged lenses, arctic clothing, guns improperly degreased, etc., all contributed in some measure to the lack of complete control of the firing rate.

It could be argued that the rate must be erratic in order to have uniform aiming conditions. The shooter is not likely to arrive at the optimum time to pull the trigger in a regular cadence. However, the error contributed by changing gun temperature conditions (caused by the irregular firing cadence) is small compared to the total dispersion throughout most of the testing.

Measurements of temperature, humidity, barometric pressure, and chamber pressure were taken continuously during the experiments to obtain the exact density. In all experiments in the chamber except those on 8 December 1962, the chamber was held at a constant temperature for several hours prior to the firing. Thus, the chamber temperature was uniform and the temperature reading was taken at one point in the chamber. On 8 December, when the chamber temperature was changing

during the tests, temperature readings were taken at several points along the bullet trajectory, and readings were taken before and after each group firing.

All firing of guns, except on 9 November and on 13 December, was performed by the same shooter. A single well-defined aiming point was used for each 10-shot group. As will be observed, an excessively large number of targets were taken only on 8 December. Shooter fatigue should not be a significant factor even on 8 December because of more agreeable temperatures on that date.

In general, it can be said that every attempt was made to remove all errors except the ballistic errors. Where this was not possible, firings were performed to assess the magnitude of the extraneous contribution or the data have been manipulated to remove the effect. Data variation was treated by averaging or by normal curve fitting techniques.

DATA REDUCTION. Each impact in every ten-shot group was recorded with its coordinate values in an orthogonal coordinate system with arbitrary origin. Measurements were made with respect to the centroid of the signature left by the bullet in passing through the paper.

From the coordinate values, the following measures were determined for each group: maximum spread, maximum lateral spread, maximum vertical spread, and the standard deviation of the group about the mean point of impact.

In some instances, one or several of the bullets were in a yawing attitude as they passed through the target. Where this yaw was discernible, measurements of the major axis and minor axis of the signature were made, and from this and the known geometry of the bullet, a computation of angle of yaw was made.

RESULTS. Table 1 gives the results for all targets fired during this experiment.

The data from Table 1 have been plotted in Figs. 6, 7, and 8 so that the variation in group size is shown as the firing conditions change. Several methods have been chosen in order to emphasize certain factors which might evade casual observation. Each of the graphs will be discussed in subsequent paragraphs with the object of presenting the data in the manner used and the conclusions one can reach from the data.

Fig. 6 shows the average maximum spread as a function of air density for the Remington rifles, the AR-15 rifles, and the M-14 rifles, respectively. Shown also are the temperatures at which the data were taken.

TABLE 1. SUMMARY OF CONFIRMATORY TESTS RESULTS.

Target No.	Date Fired	Dry Bulb Temp. °F	Wet Bulb Temp °F	Barometic Pressure In. Hg.	Air Density lbs/ft³	Gun	Twist 1 Turn/Ins.	Maximum Spread In.	Maximum Lateral Spread In.	Maximum Vertical Spread In.	Standard Deviation In.	Average Yaw Degrees	Target Range Ft.
A-1	9 Nov	-25	-26	29.98	.091825	Remington	1 - 14	7.95	7.10	6.40	3.05	10°	220
A-2	9 Nov	-25	-26	29.98	.091825	AR-15 No 1	1 - 14	7.20	5.70	6.95	2.38	9°	220
A-3	9 Nov	-25	-26	29.98	.091825	Remington	1 - 12	1.55	.97	1.49	.51		220
A-4	9 Nov	-25	-26	29.98	.091825	AR-15 No 2	1 - 14	5.60	4.48	4.85	2.31	11°	220
B-1	16 Nov	-45	-45	29.98	.09587	Remington	1 - 10	2.50	2.50	1.55	.83		220
B-2	16 Nov	-45	-45	29.98	.09587	Remington	1 - 12	1.70	.92	1.70	.56		220
B-3	16 Nov	-45	-45	29.98	.09587	Remington	1 - 14	11.90	11.80	9.63	5.00	11°	220
B-4	16 Nov	-45	-45	29.98	.09587	AR-15 No 1	1 - 14	2.98	2.50	1.98	.99	16°	160
B-5	16 Nov	-45	-45	29.98	.09587	AR-15 No 1	1 - 14	9.65	8.58	9.00	4.42	12°	220
C-1	23 Nov	-45	-45	30.29	.096890	Remington	1 - 14	11.08	10.92	8.34	4.46	11°	220
C-2	23 Nov	-45	-45	30.29	.096890	Remington	1 - 14	11.60	11.15	10.20	5.12	11°	220
C-3	23 Nov	-45	-45	30.29	.096890	Remington	1 - 12	2.20	.77	2.15	.64		220
C-4	23 Nov	-45	-45	30.29	.096890	Remington	1 - 12	1.53	1.50	1.17	.72		220
C-5	23 Nov	-45	-45	30.29	.096890	Remington	1 - 10	1.70	1.40	1.70	.59		220
C-6	23 Nov	-45	-45	30.29	.096890	Remington	1 - 10	1.90	1.09	1.89	.77		220
C-7	23 Nov	-45	-45	30.29	.096890	AR-15 No 1	1 - 14	11.68	8.37	11.41	4.61	12°	220
C-8	23 Nov	-45	-45	30.29	.096890	AR-15 No 1	1 - 14	11.83	11.82	9.87	4.85	14°	220
C-9	23 Nov	-45	-45	30.29	.096890	AR-15 No 2	1 - 14	10.30	8.75	9.97	4.51	12°	220
C-10	23 Nov	-45	-45	30.29	.096890	AR-15 No 2	1 - 14	13.85	13.38	8.83	4.84	12°	220
D-1	24 Nov	58	42	30.33	.07705	Remington	1 - 14	5.50	5.15	2.10	1.59		220
D-2	24 Nov	58	42	30.33	.07705	Remington	1 - 14	7.13	2.65	6.61	1.65		220
D-3	24 Nov	58	42	30.33	.07705	Remington	1 - 10	1.76	1.52	1.10	.62		220
D-4	24 Nov	58	48	30.33	.07678	Remington	1 - 12	1.25	.98	.82	.37		220
D-5	24 Nov	58	42	30.33	.07705	AR-15 No 1	1 - 14	4.09	4.09	1.43	1.17		220
D-6	24 Nov	51	45	30.33	.07650	AR-15 No 1	1 - 14	3.60	3.00	2.70	1.14		220
D-7	24 Nov	58	42	30.33	.07705	AR-15 No 2	1 - 14	1.91	1.91	.67	1.98		220
D-8	24 Nov	62	48	30.33	.07620	AR-15 No 2	1 - 14	1.74	1.55	1.54	.63		220
D-9	24 Nov	62	48	30.33	.07620	AR-15 No 3	1 - 12	2.04	1.82	1.68	.76		220
D-10	24 Nov	62	48	30.33	.07620	AR-15 No 3	1 - 12	2.44	2.43	1.94	.92		220
D-11	24 Nov	65	48	30.33	.07579	AR-15 No 4	1 - 12	2.55	1.69	2.28	.82		220
D-12	24 Nov	65	48	30.33	.07579	AR-15 No 4	1 - 12	3.08	1.82	2.75	1.31		220

[1] Note

TABLE I. (Continued)

Target No.	Date Fired	Dry Bulb Temp °F	Wet Bulb Temp °F	Barometic Pressure In. Hg.	Air Density LBS/FT^3	Gun	Twist 1 Turn/Ins.	Maximum Spread In.	Maximum Lateral Spread In.	Maximum Vertical Spread In.	Standard Deviation In.	Average Yaw Degrees	Target Range Ft.	Note
E-1	29 Nov	-65	-65	30.01	.100857	Remington	1 - 12	.61	.49	.61	.28		220	2
E-2	29 Nov	-65	-65	30.01	.100857	Remington	1 - 14	15.10	14.24	12.92	6.64	8°	220	2
E-3	29 Nov	-65	-65	30.01	.100857	AR-15 No 3	1 - 12	4.10	2.73	4.02	1.54		220	
E-4	29 Nov	-65	-65	30.01	.100857	AR-15 No 3	1 - 12	4.20	3.13	4.12	1.54		220	
E-5	29 Nov	-65	-65	30.01	.100857	AR-15 No 4	1 - 12	5.42	4.29	4.58	1.75		220	
E-6	29 Nov	-65	-65	30.01	.100857	AR-15 No 4	1 - 12	4.62	2.42	4.57	1.46		220	
E-7	29 Nov	-65	-65	30.01	.100857	AR-15 No 1	1 - 14	14.30	12.40	11.28	6.83	12	220	
E-8	29 Nov	-65	-65	30.01	.100857	AR-15 No 1	1 - 14	13.05	10.85	10.80	5.85	13	220	
E-9	29 Nov	-65	-65	30.01	.100857	AR-15 No 2	1 - 14	12.95	12.84	10.63	5.75	14	220	
E-10	29 Nov	-65	-65	30.01	.100857	AR-15 No 2	1 - 14	13.25	12.50	9.60	7.36	13	220	
F-1	1 Dec	-65	-65	29.94	.100666	Remington	1 - 12	2.13	1.97	1.57	.71		220	
F-2	1 Dec	-65	-65	29.94	.100666	Remington	1 - 12	2.43	1.36	1.40	.51		220	
F-3	1 Dec	-65	-65	29.94	.100666	Remington	1 - 12	3.09	3.06	1.49	.87		220	
F-4	1 Dec	-65	-65	29.94	.100666	Remington	1 - 12	1.50	1.42	.91	.44		220	..3
F-5	1 Dec	-65	-65	29.94	.100666	Remington	1 - 14	2.53	2.13	1.37	.71		220	..3
F-6	1 Dec	-65	-65	29.94	.100666	Remington	1 - 14	15.84	14.63	14.40	7.10	12	220	
F-7	1 Dec	-65	-65	29.94	.100666	Remington	1 - 14	14.85	14.25	13.09	6.71	12	220	
F-8	1 Dec	-65	-65	29.94	.100666	AR-15 No 1	1 - 14	12.42	10.38	11.27	5.64	14	220	
F-9	1 Dec	-65	-65	29.94	.100666	AR-15 No 1	1 - 14	14.77	9.87	12.60	5.74	11	220	
F-10	1 Dec	-65	-65	29.94	.100666	AR-15 No 2	1 - 14	12.72	12.66	11.68	5.84	18	220	
F-11	1 Dec	-65	-65	29.94	.100666	AR-15 No 2	1 - 14	12.86	9.17	12.77	5.71	13	220	
F-12	1 Dec	-65	-65	29.94	.100666	AR-15 No 3	1 - 12	2.05	1.87	1.67	.85		220	
F-13	1 Dec	-65	-65	29.94	.100666	AR-15 No 3	1 - 12	4.55	3.09	4.18	1.79		220	
F-14	1 Dec	-65	-65	29.94	.100666	AR-15 No 4	1 - 12	4.40	3.55	4.38	1.81		220	
F-15	1 Dec	-65	-65	29.94	.100666	AR-15 No 4	1 - 12	6.77	4.44	6.00	1.88		220	
F-16	1 Dec	-65	-65	29.94	.100666	M-14 No 1	1 - 12	3.60	2.80	3.16	1.66		220	..4
F-17	1 Dec	-65	-65	29.94	.100666	M-14 No 1	1 - 12	5.20	2.51	4.85	1.72		220	..4
F-18	1 Dec	-65	-65	29.94	.100666	M-14 No 2	1 - 12	6.22	1.65	6.20	1.90		220	
F-19	1 Dec	-65	-65	29.94	.100666	M-14 No 2	1 - 12	5.90	2.60	5.75	1.82		220	..4
F-20	1 Dec	-65	-65	29.94	.100666	AR-15 No 3	1 - 12	5.80	4.67	4.12	1.92		220	..4
F-21	1 Dec	-65	-65	29.94	.100666	AR-15 No 3	1 - 12	7.00	4.32	6.95	2.18		220	..4

TABLE 1. (Continued).

Target No.	Date Fired	Dry Bulb Temp °F	Wet Bulb Temp °F	Barometic Pressure In. Hg.	Air Density lbs/ft³	GUN	Twist 1 Turn/ins.	Maximum Spread in.	Maximum Lateral Spread in.	Maximum Vertical Spread in.	Standard Deviation in.	Average Yaw Degrees	Target Range ft.	Note
G-1	6 Dec	-24	-25	29.79	.090675	Remington	1 - 12	1.20	1.10	.43	.39		220	
G-2	6 Dec	-24	-25	29.79	.090675	Remington	1 - 12	1.32	.90	1.05	.33		220	
G-3	6 Dec	-24	-25	29.79	.090675	Remington	1 - 14	7.55	7.37	3,87	2.76	12	220	
G-4	6 Dec	-24	-25	29.79	.090675	Remington	1 - 14	8,75	7.90	6.05	3.34	10	220	
G-5	6 Dec	-24	-25	29.79	.090675	AR-15 No 4	1 - 12	2.18	1.15	1.60	.72		220	
G-6	6 Dec	-24	-25	29.79	.090675	AR-15 No 4	1 - 12	2.30	1.82	1.98	.75		220	
G-7	6 Dec	-24	-25	29.79	.090675	AR-15 No 1	1 - 14	7.00	6.70	5.90	2.98	12	220	
G-8	6 Dec	-24	-25	29.79	.090675	AR-15 No 1	1 - 14	7.58	6.62	6.67	3.11	10	220	
G-9	6 Dec	-24	-25	29.79	.090675	M-14 No 1	1 - 12	3.26	1.58	2.03	.98		220	
G-10	6 Dec	-24	-25	29.79	.090675	M-14 No 1	1 - 12	2.66	1.60	2.60	1.01		220	
H-1	7 Dec	-25		29.99	.0914752	AR-15 No 2	1 - 14	8.10	8.10	4.45	3.33	14	220	
H-2	7 Dec	-25		29.99	.0914752	AR-15 No 2	1 - 14	7.50	6.70	5.78	3.31	12	220	
H-3	7 Dec	-25		29.99	.0914752	AR-15 No 2	1 - 14	11.64	8.63	7.95	4.04	12	220	
H-4	7 Dec	-25		29.99	.0914752	AR-15 No 2	1 - 14	6.63	6.60	6.35	2.87	10	220	
H-5	7 Dec	-25		29.99	.0914752	AR-15 No 3	1 - 12	1.80	1.25	1.58	.64		220	
H-6	7 Dec	-25		29.99	.0914752	AR-15 No 3	1 - 12	2.48	1.85	2.06	.98		220	
H-7	7 Dec	-25		29.99	.0914752	AR-15 No 3	1 - 12	2.03	1.16	1.91	.72		220	
H-8	7 Dec	-25		29.99	.0914752	AR-15 No 3	1 - 12	2.28	1.56	2.11	.85		220	
H-9	7 Dec	-25		29.99	.0914752	M-14 No 2	1 - 12	2.78	2.36	2.25	1.04		220	
H-10	7 Dec	-25		29.99	.0914752	M-14 No 2	1 - 12	4.37	3.25	3.87	1.49		220	
I-1	8 Dec	0	0	29.80	.0859507	Remington	1 - 14	5.79	4.00	4.19	1.53		220	
I-2	8 Dec	0	0	29.80	.0859507	Remington	1 - 14	3.13	2.92	1.13	.83		220	
I-3	8 Dec	0	0	29.80	.0859507	Remington	1 - 14	4.83	4.61	1.43	1.38		220	
I-4	8 Dec	0	0	29.80	.0859507	Remington	1 - 12	2.08	1.37	1.57	.50		220	
I-5	8 Dec	0	0	29.80	.0859507	Remington	1 - 12	2.49	2.21	1.15	.70		220	
I-6	8 Dec	0	0	29.80	.0859507	Remington	1 - 12	2.41	1.65	1.76	.70		220	
I-7	8 Dec	0	0	29.80	.0859507	Remington	1 - 12	2.23	1.66	1.49	.71		220	
I-8	8 Dec	0	0	29.80	.0859507	AR-15 No 3	1 - 12	2.98	2.36	1.82	.86		220	
I-9	8 Dec	0	0	29.80	.0859507	AR-15 No 3	1 - 12	3.31	2.52	2.10	1.01		220	
I-10	8 Dec	0	0	29.80	.0859507	AR-15 No 3	1 - 12	3.17	2.78	1.52	. 71		220	
I-11	8 Dec	0	0	29.80	.0859507	AR-15 No3	1 - 12	2.41	2.04	1.29	.77		220	
I-12	8 Dec	0	0	29.80	.0859507	AR-15 No 2	1 - 14	4.22	3.54	2.29	1.27		220	

TABLE 1. (Continued).

Target No.	Date Fired	Dry Bulb Temp °F	Wet Bulb Temp °F	Barometric Pressure In. Hg.	Air Density lbs/ft³	GUN	Twist 1 Turn/Ins.	Maximum Spread In.	Maximum Lateral Spread In.	Maximum Vertical Spread In.	Standard Deviation In.	Average Yaw Degrees	Target Range Ft	Note
1-13	8 Dec	0	0	29.80	.0859507	AR-15 No 2	1 - 14	4.12	2.78	3.04	1.25		220	
1-14	8 Dec	0	0	29.80	.0859507	AR-15 No 2	1 - 14	3.45	1.98	2.83	1.16		220	
1-15	8 Dec	0	0	29.80	.0859507	AR-15 No 2	1 - 14	5.46	4.06	3.65	1.53		220	
1-16	8 Dec	0	0	29.80	.0859507	AR-15 No 1	1 - 14	5.73	3.78	4.31	1.48		220	
1-17	8 Dec	0	0	29.80	.0859507	AR-15 No 1	1 - 14	4.17	2.43	3.39	1.16		220	
1-18	8 Dec	0	0	29.80	.0859507	AR-15 No 1	1 - 14	4.34	1.21	4.17	1.09		220	
1-19	8 Dec	0	0	29.80	.0859507	AR-15 No 1	1 - 14	5.61	3.65	4.26	1.49		220	
1-20	8 Dec	0	0	29.77	.0858631	AR-15 No 4	1 - 12	3.19	1.95	2.52	1.16		220	
1-21	8 Dec	0	0	29.77	.0858631	AR-15 No 4	1 - 12	2.08	1.67	1.66	.69		220	
1-22	8 Dec	0	0	29.77	.0858631	AR-15 No 4	1 - 12	3.27	1.47	2.95	1.00		220	
1-23	8 Dec	0	0	29.77	.0858631	AR-15 No 4	1 - 12	2.67	2.34	2.66	1.00		220	
1-24	8 Dec	0	0	29.77	.0858631	M-14 No 1	1 - 12	3.70	2.34	3.42	1.25		220	
1-25	8 Dec	0	0	29.77	.0858631	M-14 No 1	1 - 12	2.98	1.39	2.91	1.03		220	
1-26	8 Dec	0	0	29.77	.0858631	M-14 No 2	1 - 12	5.30	2.78	4.74	1.63		220	
1-27	8 Dec	0	0	29.77	.0858631	M-14 No 2	1 - 12	3.35	2.41	2.98	1.13		220	
1-28	8 Dec	0	0	29.77	.0858631	Remington	1 - 14	1.53	1.23	1.52	.53		220	
1-29	8 Dec	5	5	29.80	.085007	Remington	1 - 14	2.16	1.83	1.63	.75		220	
1-30	8 Dec	10	10	29.80	.084078	Remington	1 - 14	4.00	3.03	2.79	1.17		220	
1-31	8 Dec	12	12	29.80	.083719	Remington	1 - 14	1.66	1.62	.93	.62		220	
1-32	8 Dec	15	15	29.80	.083160	Remington	1 - 14	3.02	.45	.45	.88		220	
1-33	8 Dec	16	16	29.80	.083998	Remington	1 - 12	1.96	1.93	.87	.60		220	
1-34	8 Dec	16	16	29.80	.082998	Remington	1 - 12	1.09	.67	1.01	.36		220	
1-35	8 Dec	20	20	29.80	.08230	AR-15 No 4	1 - 12	2.55	1.59	2.26	.95		220	
1-36	8 Dec	20	20	29.80	.08230	AR-15 No 4	1 - 12	2.41	1.71	2.35	.92		220	
1-37	8 Dec	17	17	29.80	.082810	AR-15 No 1	1 - 14	1.58	1.55	1.42	.65		220	
1-38	8 Dec	17	17	29.80	.082810	AR-15 No 1	1 - 14	2.30	2.12	1.92	.85		220	
1-39	8 Dec	16	16	29.80	.082998	AR-15 No 3	1 - 12	2.45	2.32	1.56	.83		220	
1-40	8 Dec	16	16	29.80	.082998	AR-15 No 3	1 - 12	2.55	.95	2.54	.76		220	
1-41	8 Dec	15	15	29.80	.083160	AR-15 No 2	1 - 14	1.68	1.24	1.66	.60		220	
1-42	8 Dec	15	15	29.80	.083160	AR-15 No 2	1 - 14	2.83	2.14	2.55	1.09		220	
1-43	8 Dec	15	15	29.80	.083160	M-14	1 - 12	4.22	1.48	4.21	1.17		220	
1-44	8 Dec	15	15	29.80	.083160	M-14	1 - 12	2.45	1.74	2.42	.85		220	

TABLE 1. (Continued)

Target No.	Date Fired	Dry Bulb Temp °F	Wet Bulb Temp °F	Barometic Pressure in. Hg.	Air Density lbs/ft³	Gun	Twist 1 Turn/Ins.	Maximum Spread In.	Maximum Lateral Spread In.	Maximum Vertical Spread In.	Standard Deviation	Average Yaw Degrees	Target Range Ft.	Note
J-1	13 Dec	13	0	30.445		AR-15 No 2	1 - 14						22	5
J-2	13 Dec	13	.0	30.45		AR-15 No. 4	1 - 12						22	5
J-3	13 Dec	13	0	30.46	.085423	AR-15 No 2	1 - 14	4.68	2.43	4.00	1.53		220	
J-4	13 Dec	14	0	30.46	.085231	AR-15 No 2	1 - 14	3.55	3.18	1.58	1.18		220	
J-5	13 Dec	14	0	30.46	.085231	AR-15 No 4	1 - 12	2.93	1.22	2.66	.67		220	
J-6	13 Dec	14	0	30.465	.085231	AR-15 No 4	1 - 12	2.36	1.94	1.34	.45		220	

NOTES:

1 - Short Range
2 - 5 Shot Group
3 - Western Cartridges
4 - Iron Sights
5 - Warm-up

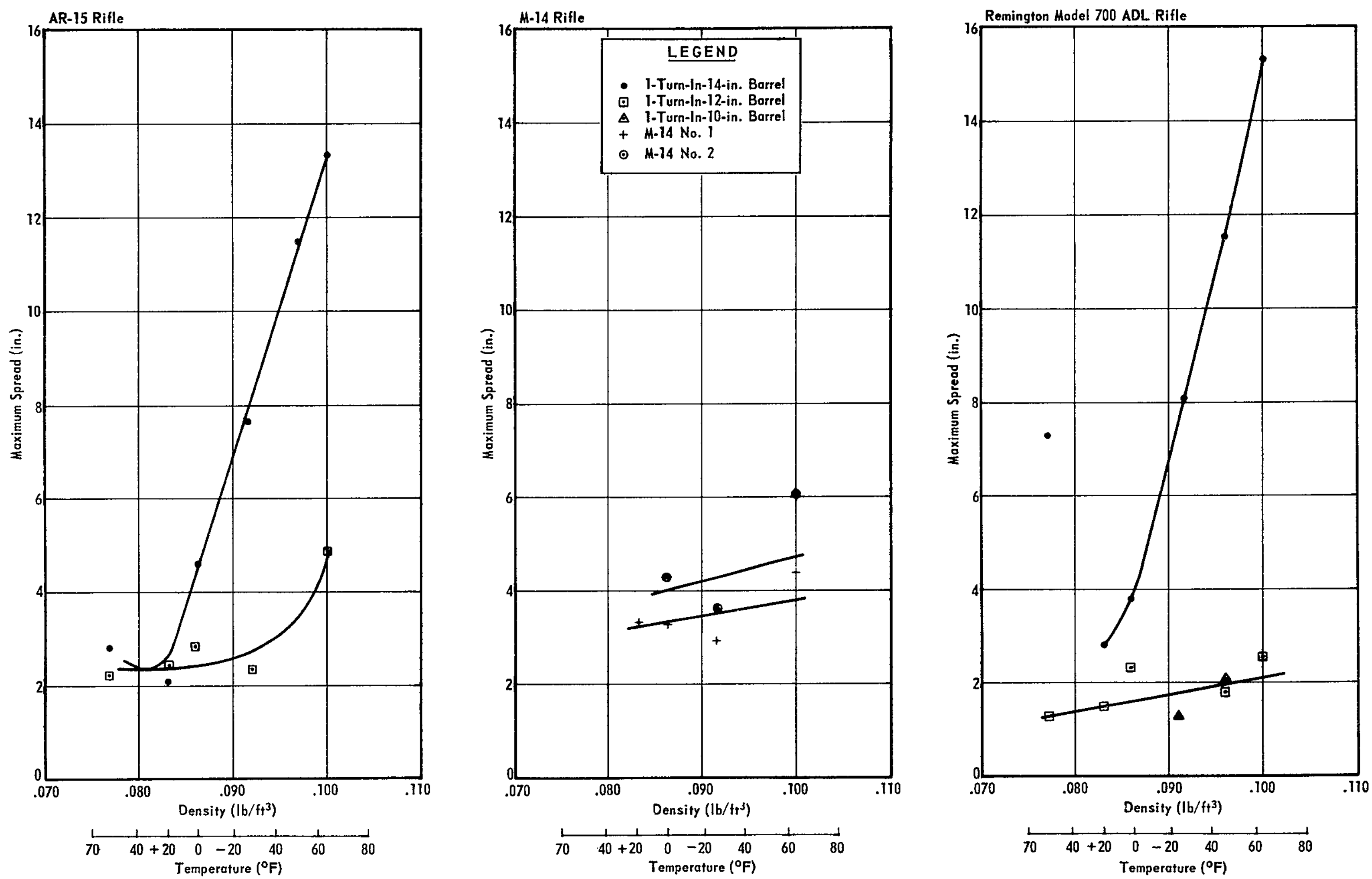

Fig. 6: Maximum Spreads vs Air Density and Temperature.

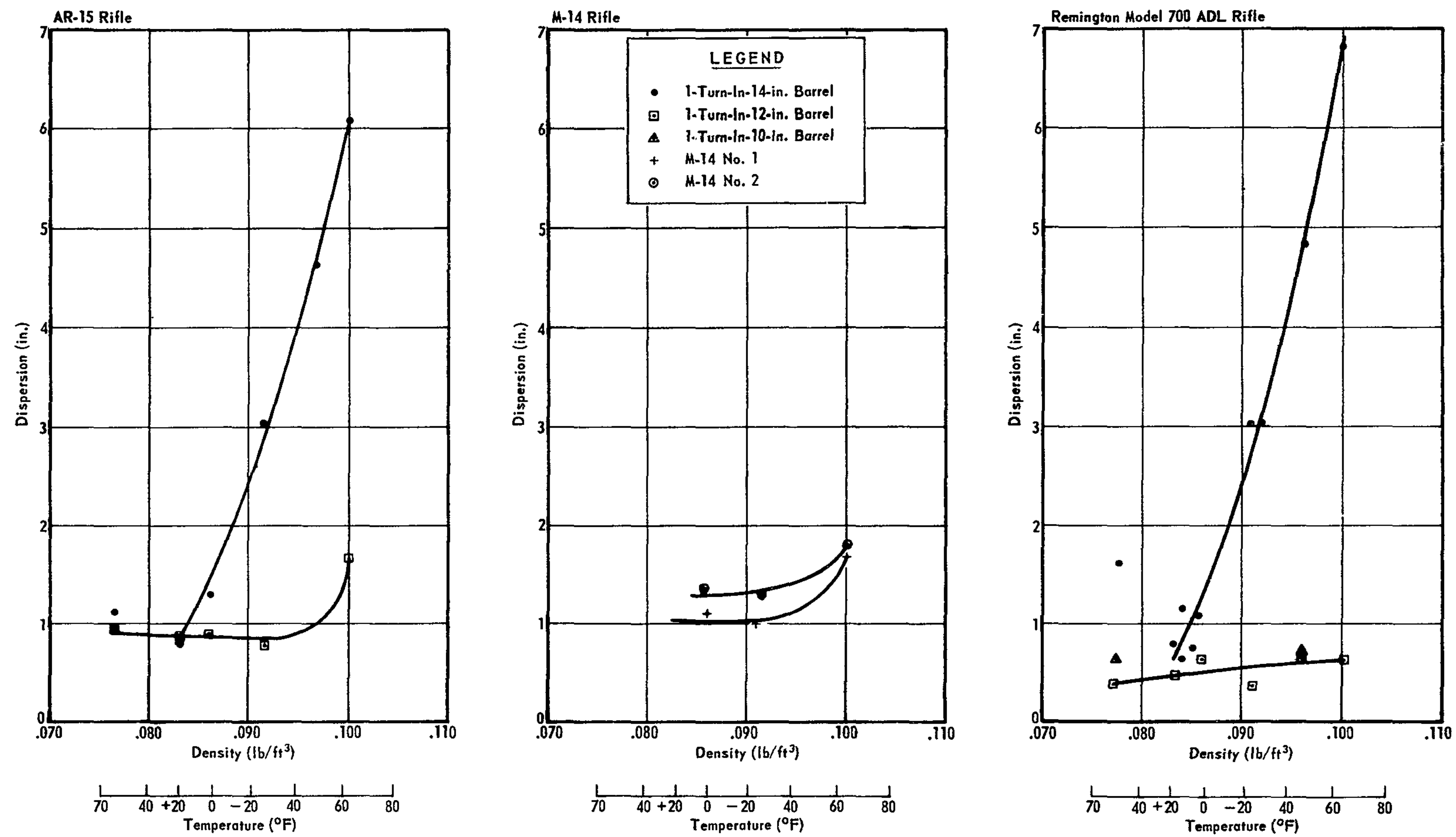

Fig. 7: Average Dispersion vs Air Density and Temperature.

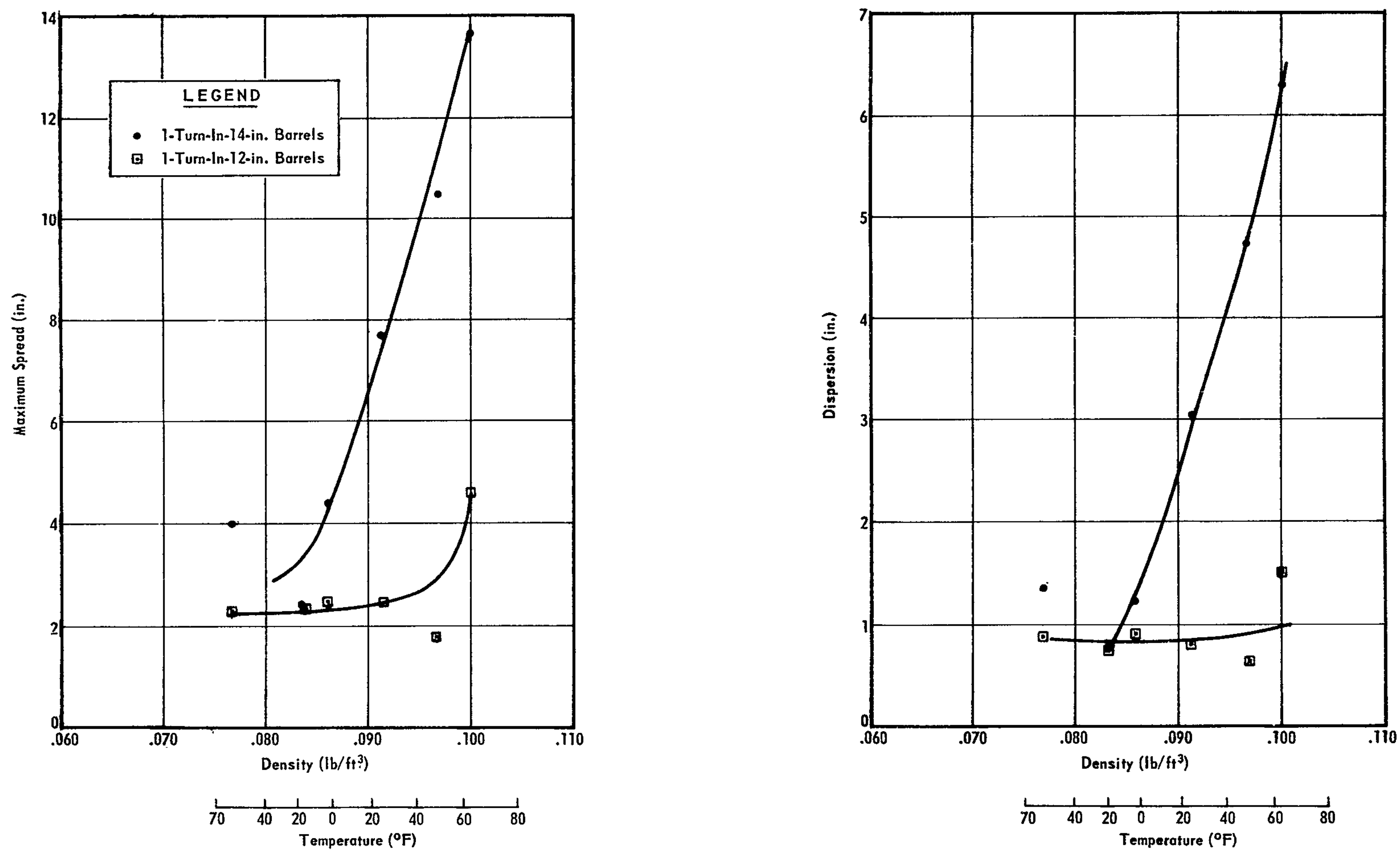

Fig. 8: Average Maximum Spreads and Dispersions vs Air Density and Temperature.

In Fig. 6 it can be seen that there is a severe dispersion problem with the Remington caliber 0.223 bullet in the one-turn-in-14-in. barrels when the air density reaches 0.085 lb per ft^3, which corresponds to 5° F at sea level. This corresponds to a computed stability factor for these guns and bullet of 1.02, as determined in the computational techniques (Fig. 5). The same bullets from the one-turn-in-12-in. barrels show no stability problems down to -65° F. The computationally derived stability factor for this condition is 1.18, quite sufficient for a stable bullet.

Fig. 7 shows the average dispersion (standard deviation) for the Remington, AR-15, and M-14 rifles as a function of air density. As would be expected the same results as pointed out above are apparent and the same comments are appropriate.

As a matter of interest, all of the groups for the caliber 0.223 rifles were averaged for the one-turn-in-14-in. barrels and one-turn-in-12-in. barrels and plotted against air density. Fig. 8 shows the average maximum spread and the average standard deviation. From these composite curves, it now appears that excessive dispersion occurs at a density of about 0.0865 lb per ft^3. This corresponds to a computed stability factor of 1.01. This air density occurs at approximately 0° F at sea level and is almost exactly the computed critical point.

It can be seen from the graphs that the group sizes for the one-turn-in-12-in. barrels increase at -65° F. This is not considered to be an inherent stability factor, since all group sizes increased at -65° F. These increases are believed to have resulted from discomfort of the shooter, fogging of the scope, and poor performance of the ammunition at this temperature. However, such a temperature occurs so rarely and over such small land regions on the earth that the military significance of the -65° F data is slight for that reason alone.

From the above data it can be determined that there is a severe stability problem using the Remington caliber .223 ammunition in the one-turn-in-14-in. barrel. It can be further determined that the one-turn-in-12-in. barrel satisfactorily stabilizes the bullet far below -65° F. Computations show that a one-turn-in-13-in. barrel would be a sufficient twist for the Remington bullet for all practical combat temperatures; however, no adverse effects result from using a one-turn-in-12-in. barrel, and it affords an over stable margin that will permit use of possible future bullets of improved form.

BULLET LETHALITY

One possible consequence of changing the twist of the AR-15 barrel to improve stability would be a reduced bullet lethality. To determine

if this change would result, a series of impact tests was conducted by Aerojet-General Corporation using both the one-turn-in-14-in. barrel and the one-turn-in-12-in. barrel.

In order to provide a more comprehensive coverage of the subject, the following discussion on the mechanism of wounding is quoted from Wound Ballistics (pp 129, 130, 132, 136, 166) as published by the Medical Department of the United States Army. The following applicable quotations are extracted from this book:

1. "Pitch of rifling through determining the rate of spin is a factor in controlling the stability of the bullet in flight and in turn the degree of yaw on impact. The rate of spin in the usual military rifle is high. With the .30 caliber flat-base bullet at a muzzle velocity of 2,700 f.p.s. and a rifling pitch of 30 calibers, the spin is more than 3,500 revolutions a second. This spin is only adequate to stabilize the 150-grain bullet in air flight. The spin has a negligible effect in maintaining the bullet in a point-on position in denser mediums, such as water or tissue."

2. "However, density of resistant materials is a direct factor on the retardation and other motions of a missile. Water with a density 800 times that of air and tissues of slightly greater densities act much as a magnifying of all of the retardations, yaw, and gyrations of the bullet 800 or more times. A very slight tip or yaw will become one of more than 50° by the time a .30-caliber 110-grain solid bullet homologous in shape with the 150-grain flat-base bullet has traversed 3 in. of water. Not infrequently, the increase in yaw will exceed 100°. Changing from one density to another also induces marked variations in degree of yaw.

"This, of course, immediately changes the area of presentation; a bullet enters tissue point on but in a few inches may be tipped up to 90° or more and the presentation area is broadside. The forces of spin are still operating, however, through the overturning couple and tend to stabilize and maintain the bullet in point-on flight. Consequently, in another few inches, the bullet is again point-on and may leave the body through a small exit wound. Neither entrance nor exit wounds give any idea regarding the extensive interior destruction occasioned by the extreme tip and periodic bullet gyrations within the tissues."

3. "Yaws of more than 170° have been observed in bullets in passing through 6 inches of water. Theoretically, yaw can be of any value to just under 180°. A yaw of 170° increases the retardation factors 172 times and a yaw of 179°, 190 times. This readily explains why a superspeed bullet is stopped in a very few feet of a homogeneous medium such as water."

"This also explains why a super-velocity bullet is retarded so greatly in producing a casualty. The extreme retardation of such bullets can result in a wound with comparatively enormous destruction, tissue pulping, bone shattering, and other extreme manifestations only possible with the modern, fast-moving military bullet."

4. "The situation (cavity formation) in soft tissues of living animals appears (from tests) to be very similar to that described for a gel."

5. "Knowing the relationship between the permanent cavity, zone of extravasation, and the temporary cavity, the military surgeon can use this knowledge in determining the extent of the wound."

Based on the above referenced book and particularly from the above quotations, an experimental program was planned to demonstrate the relative lethality of the AR-15 rifle and the AR-15 rifle with a modified barrel. In the program, 20 percent gel was used and high-speed photographic shadow-graphs were taken of the transient or temporary cavity caused by bullets from each gun.

Two factors were felt to be important in the formation of the cavities. First, the cavity volume is important because it is a measure of the energy expended in the formation of the wound. Second, the depth at which the center of the cavity is located is important since it indicates the depth at which the maximum damage can be expected in a homogeneous target. It was assumed that if these measurements were essentially the same for both guns, then their lethalities should be the same.

Fig. 9 shows a flash X-ray composite with the bullet at four points during impact in gelatin. The bullet yaw and deformation are clearly evident from the X-ray. The point at which tumbling occurred correlates with the evidence obtained from the high-speed shadowgraphs.

This bullet was fired from the modified AR-15 rifle. Note that the bullet impacted at almost exactly zero degrees yaw. The range from rifle to impact was 50 feet. The gelatin block (12 in. x 6 in. x 6 in.) was completely disrupted during this impact and the last four exposures of the X-ray picture were lost as a result of splattering gelatin. Initial transient cavity formation is evident.

The original plan was to have flash X-ray and high-speed photographic histories of the bullet yaw and cavitation. Instrument calibration tests indicated that 12-in. cubes of gelatin were required to display the full cavitation capability of the bullet.

The low X-ray power available made it impractical to obtain X-ray coverage of the impacts. Cavitation data collection was limited to high-speed photographic methods alone.

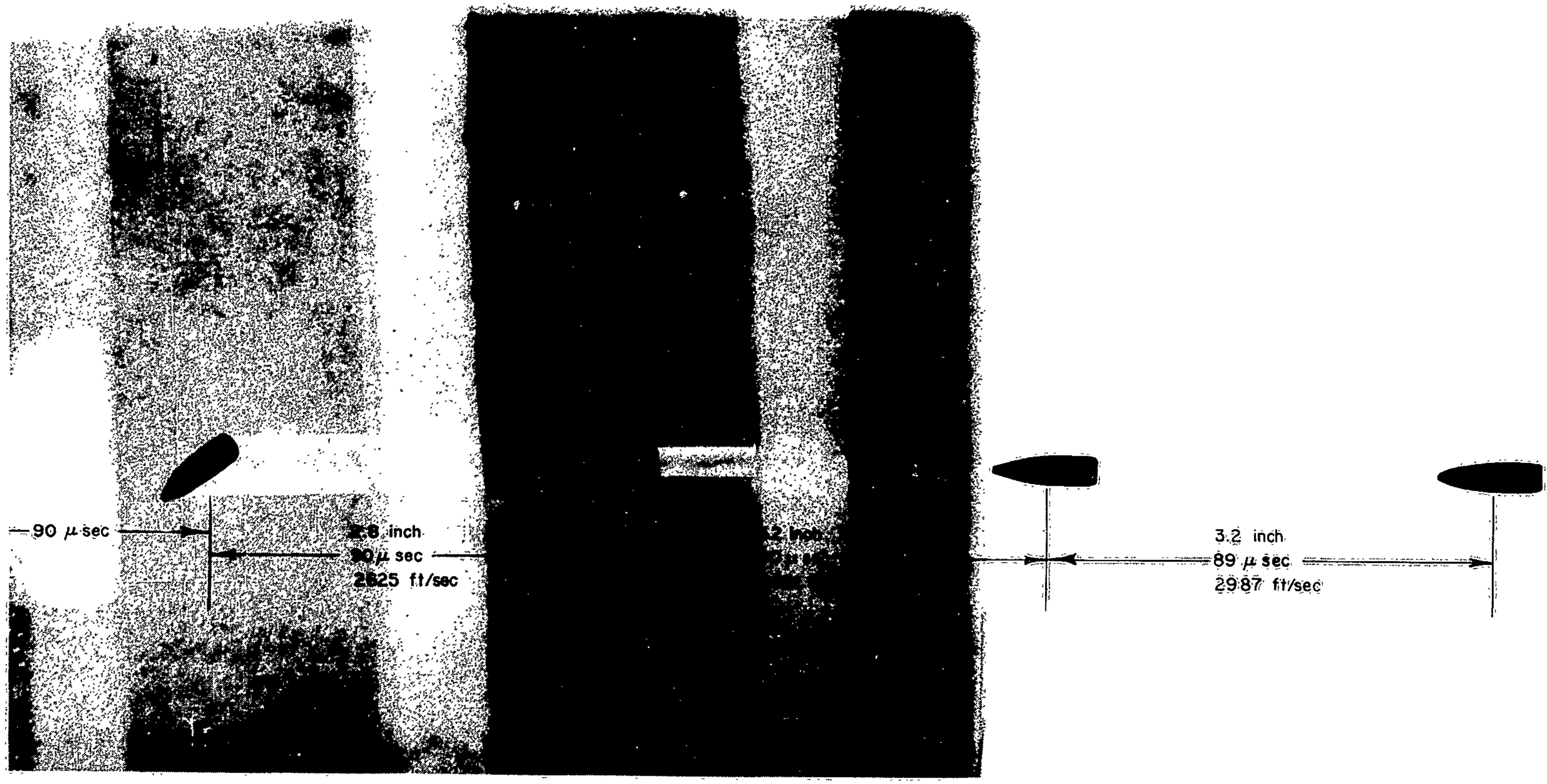

Fig. 9: Typical Flash X-Ray Showing Bullet During Impact in Gelatin Block.

Four valid tests were performed with each of two AR-15 rifles. Gun No. 1 with the standard one-turn-in-14-in. barrel and Gun No. 3 with the one-turn-in-12-in. barrel were used in these tests.

Table 2 shows the results of these tests. Measurements taken from the film were maximum cavity diameter and depth of cavity. Cavity diameter was defined to be the maximum lateral expansion of the cavity. Cavity depth was defined to be the distance from the point of entry into the gelatin to the center of the cavity at maximum diameter. Also shown are the impacting velocity as taken from chronograph screens placed immediately in front of the gelatin and the time from entry to maximum cavity. All shots referred to in Table 2 were fired at a range of 200 ft.

TABLE 2. RESULTS OF IMPACT TESTS

Test No.	Date	Maximum Cavity Diameter (in.)	Depth to Cen (in.)	Time After Entry (sec)	Striking Velocity (fps)	Rifling (in.per turn)
1	12-12-62	9.4	6	$1.5x10^{-3}$	2958	12
2	12-12-62	9.0	5	$1x10^{-3}$	3062	14
4	12-13-62	9.0	6	$1.7x10^{-3}$	3007	12
5	12-13-62	8.5	6	$1.5x10^{-3}$	3015	14
9	12-14-62	8.5	6.3	$1.5x10^{-3}$	2946	12
10	12-14-62	8.2	6	$1.5x10^{-3}$	2925	14
11	12-14-62	9.0	5	$1.4x10^{-3}$	2991	14
12	12-14-62	9.0	6	$1.5x10^{-3}$	3024	12
Gun #1	(Averages) 1 in 14 twist	8.7	5.5		2998	14
Gun #3	(Averages) 1 in 12 twist	9.0	6.1		2984	12

BULLET PENETRATION, DEFLECTION, AND BREAK-UP

Tests were performed to determine if a deflection problem exists with the caliber 0.223 bullet on impact with the limbs and twigs of trees. Limbs of pine and oak up to 5 in. in diameter were used. Both caliber 0.223 bullets and caliber .30 M-2 bullets were fired at a range of 100 yd. through the limbs and into yaw cards set at 18 ft. beyond the limbs. At this distance 90^{o} yaws were observed with both bullets. Bullets were deflected not more than 3 ft. in the 18 ft. from impact to the witness card even after penetrating 5 in. of oak. No bullet break-up was observed on impacts with wood.

On two occasions bullets were deflected and struck the ground. One was a caliber .30 and the other was a caliber .223. Both bullets broke up. It was assumed that the bullet was in a yawed condition on impact with the ground, contributing to the break-up.

It was determined as a result of these tests that impacts upon small twigs and limbs do not cause bullet break-up and do not cause serious deflections.

A study performed by the Denver Research Institute (Reference 5) involving the proper design of armor grilles contributed an empirically derived theory of deflection. Equations were derived which predict the angular change in direction experienced by a perforating projectile. Fig. 10 shows the expected angular deflection of steel cylinders impacting a mild steel plate at 45^{o} obliquity.

Although these data are worked out for steel impacting upon steel, there is no reason to believe that the same type of curve would not be appropriate for jacketed lead bullets on wood. In fact, at higher ratios of impact velocity to critical penetration velocity the deflection in the latter case might be less. The limitation of time and resources did not permit further pursuit of this investigation.

Penetration tests were carried out against armor plate, mild steel, automobile body sheet metal, oil drums, truck motors, aircraft, wood, and other materials. Some of these tests are recorded in Table 3.

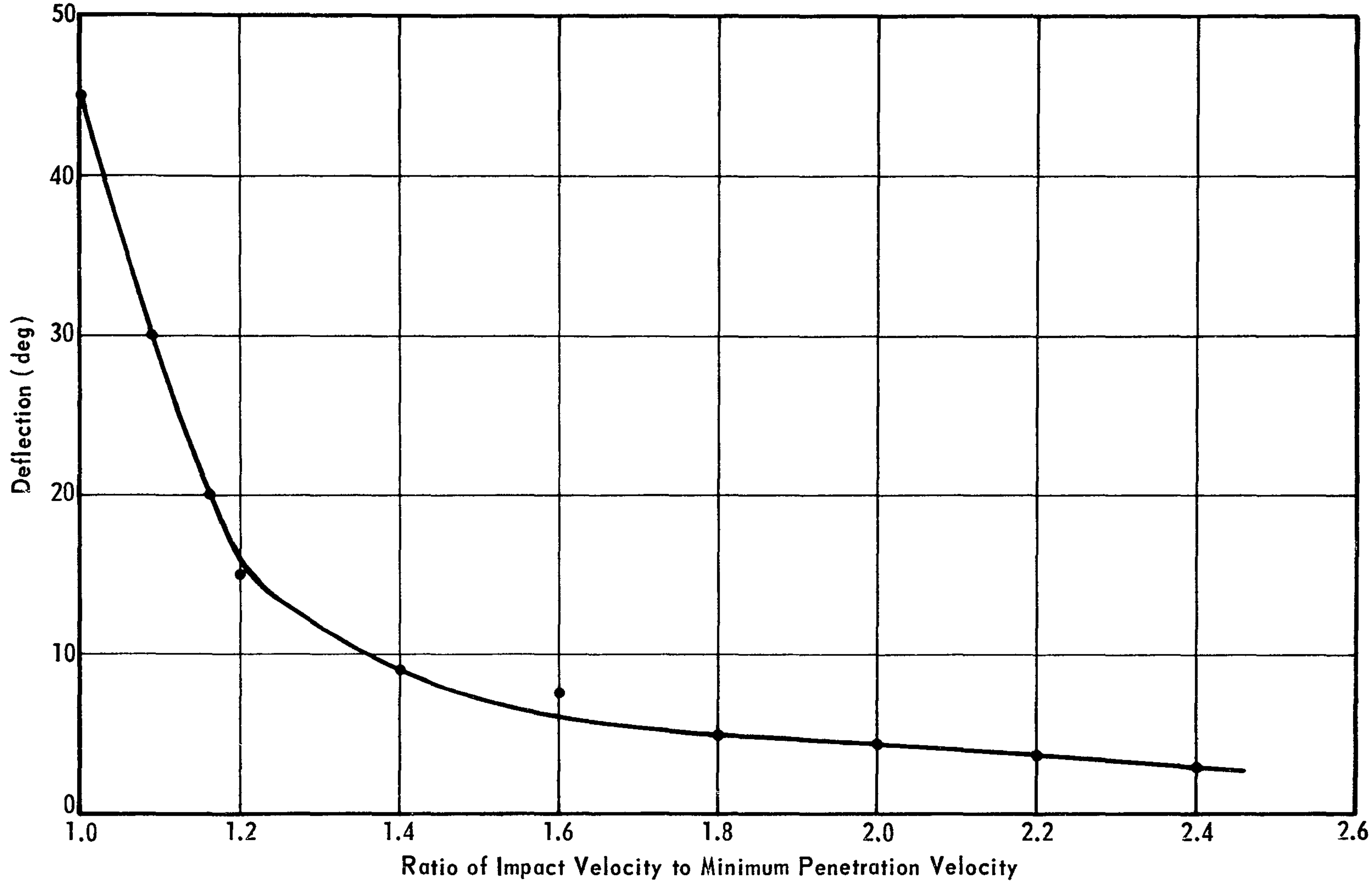

Fig. 10: Angle of Deflection vs Ratio of Impact Velocity to Minimum Penetration Velocity, Steel Cylinders Impacting Mild Steel Plate at 45° Obliquity.

TABLE 3. RESULTS OF PENETRATION TESTS OF THE CALIBER 0.223 BULLET

No.	Target	Range (yd)	Result
1	1/4-in. Mill Steel	100	Complete Penetration
2	1/4-in. Armor Plate	20	Complete Penetration
3	3/8-in. Mill Steel	100	Bulged Plate Sometimes Penetrated
4	55-Gal Drum	100	Penetrated Completely through drum
5	Jeep Body	100	Penetrated 3 spaced skin thicknesses
6	Heavy Truck	100	Penetrated hood, disrupted oil lines, did not penetrate engine block
7	Heavy Truck	100	Penetrated fuel tank completely
8	F-84 Aircraft	100	Penetrated skins, destroyed hydraulic lines after penetration

Figs. 11 through 14 show the results of some of these tests. As can be seen, the caliber 0.223 bullet is capable of penetrating and destroying military targets. Bullets were observed to break up; however, under the conditions of these tests most military bullets would be expected to break-up.

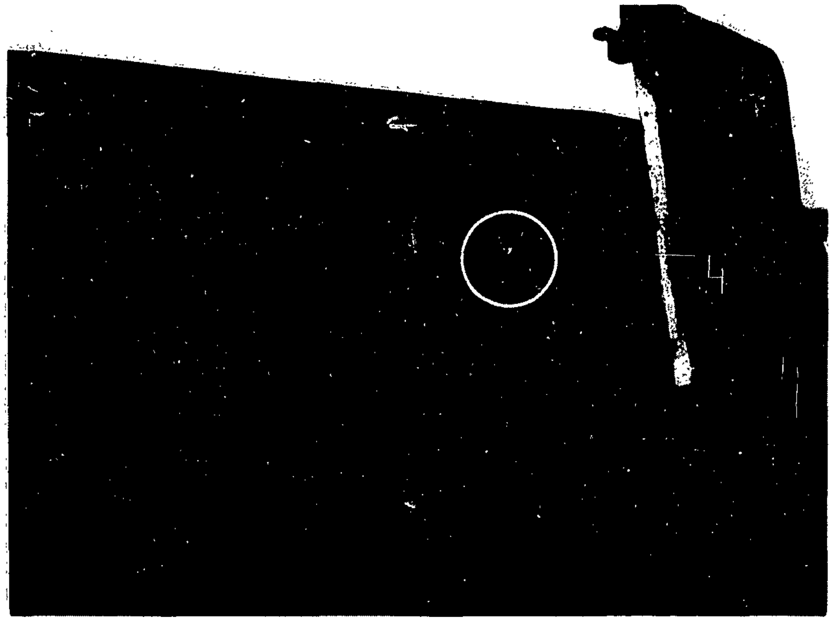

Fig. 11: Penetration Through $\frac{1}{4}$-in. Armor Plate (Exit Hole).

Fig. 12: Penetration Through 55-Gal Drum.

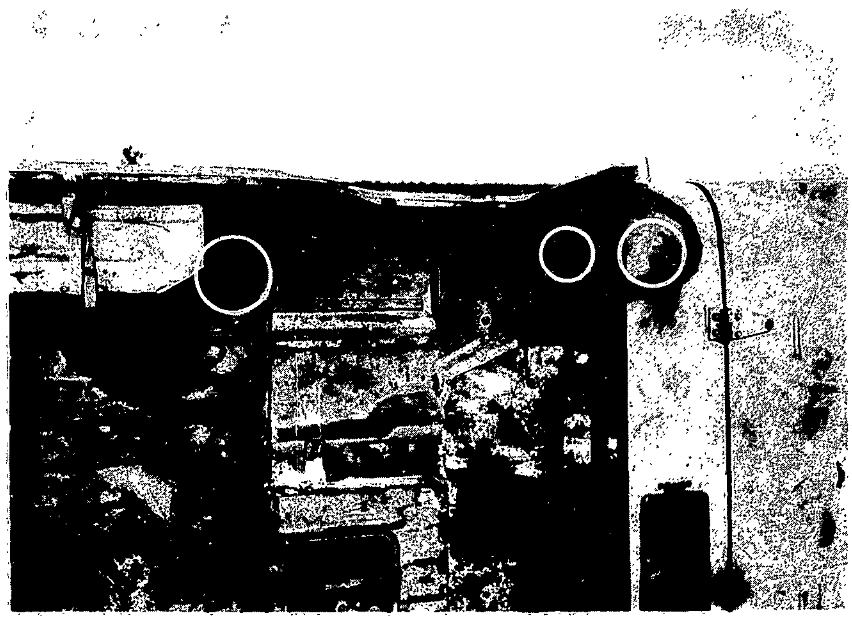

Fig. 13: Penetration Through Three, Spaced, Skin Thicknesses of a Jeep Body. Entrance Through Hood, Exit Through Rear Wheel Well.

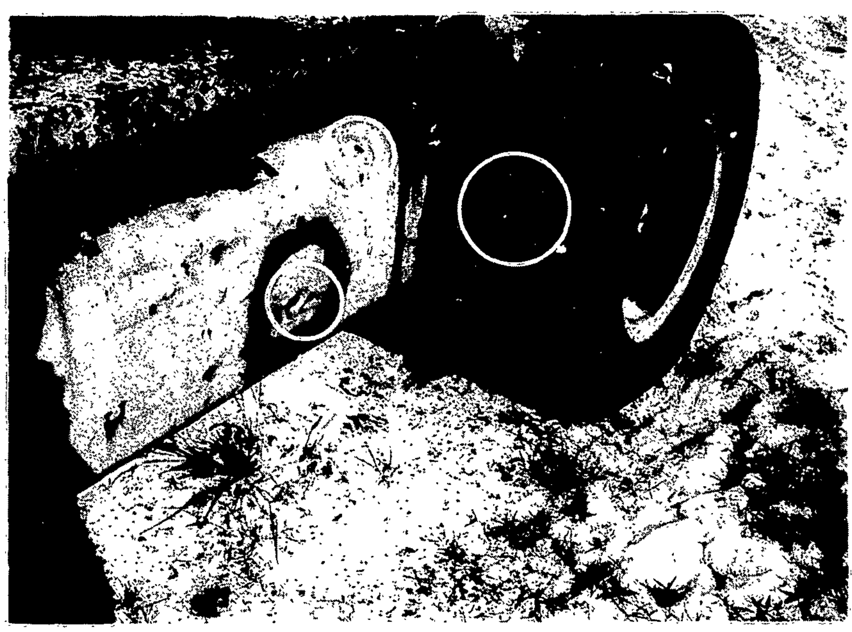

Fig. 14: Penetration of Fuel Cell, High Angle of Obliquity of Impact. Note Splatter on Mud Shield.

SECTION 4 - CONCLUSIONS

1. The Remington 0.223 caliber bullet, when fired from barrels with one-turn-in-14-in. twist is unstable under a wide variety of cold weather combat conditions.

2. Changing the twist in the barrel from one-turn-in-14-in. to one-turn-in-12-in. will stabilize the Remington 0.223 caliber bullet under all expected combat situations.

3. Changing the twist in the barrel does not reduce the lethality of the bullet.

4. Substitution of a flat-base bullet for the boat-tail bullet will result in stable projectiles from the one-turn-in-14-in. barrels, but there will be an unacceptable attendant degradation of the exterior ballistics as a result of this change.

5. The caliber 0.223 bullet is capable of penetrating and killing a wide variety of soft-material targets.

6. There are no severe deflection or break-up problems with the caliber 0.223 bullet when firing through brush and other natural cover.

REFERENCES

1. Col. E. H. Harrison, USA (Ret'd), "Development in .22 Military Rifles" American Rifleman, July 1958, pp 17-19.

2. NRA Staff, "The Armalite AR-15 Rifle", American Rifleman, June 1959, p 24.

3. W. J. Howe and E. H. Harrison, "The Armalite AR-15 Rifle", American Rifleman, May 1962, pp 17-23.

4. Wound Ballistics, U. S. Army Medical Corps, 1962.

5. R. F. Recht and T. W. Ipson, The Dynamics of Terminal Ballistics, Denver Research Institute, 1 Feb 1962.

6. McShane, Kelley and Reno, Exterior Ballistics, University of Denver Press, 1953.

APPENDIX

BULLET STABILITY COMPUTATION TECHNIQUES

A bullet is said to be stable provided its yaw decreases, approaching zero angle as the time of flight increases. The conditions for stability can be stated mathematically in the solutions to several equations involving the aerodynamic coefficients of the projectile.

Precisely, in order for a projectile to be stable, it is necessary and sufficient that the following inequality be satisfied:

$$\frac{1}{s} = \frac{4B^2 K^{-2} J_m}{A^2 \nu^2} < \frac{S_2 S_3}{S_1^2}$$

where

$$S_1 = J_N + K^2 J_H - J_D - \frac{J_A md^2}{A}$$

$$S_2 = 2J_N - 2J_D - 2 \frac{J_T md^2}{A}$$

$$S_3 = 2K^{-2} J_H + \frac{(2J_T - 2J_A) md^2}{A}$$

The J factors in the above equations are the aerodynamic coefficients of the projectile multiplied by the density factor $\frac{\rho d^3}{m}$. The following symbols are used:

s is stability factor

$$\nu = \frac{\omega_1 d}{\mu_1}$$

ρ is the density of the medium through which the bullet is traveling.

μ_1 is muzzle velocity

d is the bullet diameter

ω_1 is bullet angular velocity at the muzzle

m is the bullet mass

A is the axial moment of inertia of the bullet

B is the transverse moment of inertia of the bullet

$K^2 = \frac{B}{md^2}$ the transverse radius of gyration of the bullet

$J_N = \frac{\rho d^3}{m} K_N$ Normal force coefficient

$J_D = \frac{\rho d^3}{m} K_D$ Drag coefficient

$J_H = \frac{\rho d^3}{m} K_H$ Damping coefficient

$J_T = \frac{\rho d^3}{m} K_T$ Magnus force coefficient

$J_A = \frac{\rho d^3}{m} K_A$ Spin coefficient

$J_M = \frac{\rho d^3}{m} K_M$ Overturning coefficient

In the case considered herein, the condition for stability can be reduced to the following inequality:

$$s = \frac{A^2 \nu^2}{4B^2 K^{-2} J_{M'}} > 1$$

or in a more convenient form

$$s = \frac{A^2 \omega_1^2}{4B \ \rho d^3 \mu_1^2 K_{M'}} > 1$$

where

$$\omega_1 = 24 \pi \mu_1 N$$

ω_1 is angular velocity in radiaus per second

N is twist of rifling in turns per inch

μ_1 is muzzle velocity in feet per second

Here K_M is the overturning moment of the bullet and is approximately of the value 1 for the range of conditions herein. A and B, the axial and transverse moments of inertia, respectively, and the stability factor may be obtained in a number of ways. These include controlled firing on the spark range, firing through yaw cards, computations from bullet dimensions, and by dynamic balance tests. All of these methods yield acceptable estimates.

Once the stability factor has been determined for one set of conditions of temperature and pressure, it can be extrapolated to a new condition with a high degree of confidence. Conversion from a condition i to a condition j can be accomplished as follows:

$$s_j = s_i \frac{\rho_1}{\rho_j} \left(\frac{\omega_j}{\omega_i} \right)^2$$

or

$$s_j = s_i \frac{\rho_i}{\rho_j} \left(\frac{N_j}{N_i} \right)^2 .$$

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